COMMUNICATION SYSTEM FOR MOBILE USERS USING ADAPTIVE ANTENNA

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Related Application

[0001]   The present application claims priority to provisional applications Serial No. 60/266,684 filed on February 5, 2001; Serial No. 60/262,717 filed on January 19, 2001; and Serial No. 60/262,701 filed on January 19, 2001; each of which are incorporated by reference herein. The present application is also related to US patent application entitled; "Multiple Basestation Communication System Having Adaptive Antennas" (Attorney Docket Number PD-201005); and "Stratospheric Platforms Communication System Using Adaptive Antennas" (Attorney Docket Number PD-201015); filed simultaneously herewith and incorporated by reference herein.

Technical Field

[0002]   The present invention relates generally to a communication system and more particularly, to a communication system using a ground-based base station and a gateway station that performs beam control at the gateway station.

Background Art

[0003]   In this communication age, content providers are increasingly investigating ways in which to provide more content to users as well as interfacing with users.

[0004]   The Internet has increased the need for consumer information at high speeds. DSL and cable modems are increasing in popularity because they provide higher byte rates than telephone and modem-based systems. Providing broadband access through cable or DSL service requires increased infrastructure. That is, cables must be laid through which service is provided. Cables are time consuming and costly to provide as well as costly to maintain.

[0005]   Because of high competition, cost for providing service is an important factor. Also, providing high data rates is also an important factor.

[0006]   Limitations to the number of users may be inhibited by interference in systems. For example, for every beam having a main lobe, a parasitic number of side lobes

exist which may cause interference with beams using the same system resource such as frequency.

[0007]   It would therefore be desirable to provide a mobile communication system that is capable of rapid deployment, is easy to change, should the technology inevitably change and reduces the amount of interference with adjacent beams to permit high throughput.

Summary of the Invention

[0008]   The present invention provides a communication system that allows rapid deployment and provides interference rejection. The present invention is suitable for both fixed users such as those positioned in a building or home or for mobile users.

[0009]   In one aspect of the invention, a communication system has a high altitude device having an adaptive antenna with a plurality of main array antenna elements for generating a plurality of communication beams. The system further includes a gateway station coupled to the high altitude device. The gateway station forms a plurality of beams commands by communicating plurality of a control signals to the high altitude device station to form the communication beams.

[0010]   In a further aspect of the invention, a method of controlling a communication system comprises the steps of:

dividing a communication signal into a plurality of multiple dynamic links at the gateway station;

directing the multiple dynamic links to a plurality of base stations; and

coupling the multiple dynamic links through the plurality of base stations.

[0011]   One advantage of the invention is that due to the interference detection, system throughput is increased over conventional systems.

[0012]   Another advantage of the invention is that by locating a majority of the processing remote from the base stations, overall costs of systems may be further reduced.

[0013] Other features and advantages of the present invention using remote digital beam forming are readily apparent from the following detailed description of the best mode for carrying out the invention when taken in connection with the accompanying drawings.

Brief Description of the Drawings

[0014] Figure 1 is a system diagram of a communication system according to the present invention.

[0015] Figure 2A is a top view of a base station antenna according to the present invention.

[0016] Figure 2B is a side view of the base station antenna of Figure 2A.

[0017] Figure 2C is a side view of a panel of the base station of Figure 2A illustrating elements thereon.

[0018] Figure 2D is an alternative side view showing elements of a panel of a base station.

[0019] Figure 2E is a third alternative embodiment of elements of a panel of an antenna according to the present invention.

[0020] Figure 3 is a high level block diagrammatic view of element modules coupled to a data bus.

[0021] Figure 4 is a beam pattern for the panel illustrated in Figure 2.

[0022] Figure 5 is a block diagrammatic view of a digital beam forming circuit according to the present invention.

[0023] Figure 6 is a block diagrammatic view of a beam forming circuit using noise injection according to the present invention.

[0024]   Figure 7 is a block diagrammatic view of a base station processing circuit according to the present invention.

[0025]   Figure 8 is a block diagrammatic view of a gateway processing station according to the present invention.

[0026]   Figure 9 is a more detailed schematic view of a demultiplexing beam forming and nulling circuit according to the present invention.

[0027]   Figure 10 is an alternative for the remote processor; an adaptive digital beam forming and nulling processor according to the present invention.

[0028]   Figure 11 is an alternative nulling circuit with a limiter on the feedback path according to the present invention.

[0029]   Figure 12A is an output of a digital beam forming circuit not including limiter as shown in Figure 10.

[0030]   Figure 12B is an output of the circuit of Figure 10 with limiters at all feed-through paths.

[0031]   Figure 12C is an output of circuit shown in Figure 11 with limiter on the feed-back path, wherein the power density levels of both the weak and strong interference is successfully reduced below a threshold.

[0032]   Figure 13 is an alternative digital beam forming and nulling processor using auxiliary elements.

Best Modes For Carrying Out The Invention

[0033]   In the following description, the same reference numerals are used to identify the same components in the various views. Those skilled in the art will recognize that various other embodiments, structural changes and changes in measures may be made

without departing from the scope of the invention. The teachings of the present invention may be used for both fixed users as well as mobile users.

[0034] Referring now to Figure 1, a communications system 10 has a plurality of beams 12 that are illustrated as a plurality of circles 14 on the earth's surface. Circles 14 represent the footprint of a radiated beam onto the earth's surface. A plurality of user terminals 16M and 16F are used to illustrate mobile users and fixed users, respectively. Mobile users 16M may comprise but are not limited to automotive applications, personal digital assistant applications and cellular phone applications. Fixed user terminals 16F may, for example, comprise business-based or consumer-based communication systems. Each user terminal 16F and 16M may receive a signal with the predetermined signal strength from a communication beam or communication beams through multiple links from one or more base stations 18. The present invention is particularly advantageous for use with mobile terminals 16M. Although only two wireless basestations are illustrated, they may each represent a plurality of basestations.

[0035] Communication system 10 further includes a gateway station 20 that is coupled to terrestrial networks 22. Gateway station 20 may be coupled to a base station processing center 24. Gateway station 20 provides a links between user terminals 16F, 16M and terrestrial networks 22 through base stations 18. Gateway station 20 may be coupled to terrestrial networks 22 such as the public service telephone network, the Internet, or an intranet. Although illustrated as two separate units, gateway station 20 and processing center 24 may be combined into the same physical location.

[0036] The communication signals between base station 18 and user terminals 16M and 16F may be referred to as user links 26. User links 26 represent the transmit and receive beams from both categories of user terminals 16F, 16M and base station 18. A feeder link 28 is defined between base station 18 and gateway station 20.

[0037] Base stations 18 are used as a communication nodes for gateway station 20 and user terminals 16F and 16M. For communicating with user terminals 16M and 16F, base

stations 18 have an adaptive antenna 30 formed of panels of reconfigurable elements as will be further described below. Each base station 30 also has a directional antenna 32 for coupling to gateway station antenna 34. The coupling of antennas 32 and 34 allows base station 18 to be wireless and therefore advantageously be easily deployed. As will be described below, the pointing from both mobile terminals 16M and base station 18 may be performed electronically. Although only one gateway station 20 is illustrated in the figure, those skilled in the art would recognize that various numbers of gateway stations may be employed. Gateway station 20 has a gateway control circuit 23 that controls the content and communication with the base station 18.

[0038] Base station 18 has a controller 36 that links user terminals 16M, 16F through antenna 32 with gateway station 20. In the present example, the controller 36 is used in the return link direction to multilplex received signals from all the array element into the feeder link signals 28 as determined in the gateway station 20. Similarly in the forward link direction, controller 36 is used to de-multiplex the feeder link signals into various streams of signals for array elements to transmit.

[0039] Gateway control circuit 23 may have various circuitry coupled thereto. For example, analog or digital TV 38, an up converter 40, and a cable modem terminal shelf (CMTS) 42. CMTS 42 may be used to couple to terrestrial networks such as Internet 22. CMTS 42 may be coupled to a hub 44 that has various resources coupled thereto. The hub 44 may, for example, have a management server 46, a world wide web, e-mail or news server 48 or a proxy server 50.

[0040] Referring now to Figures 2A, 2B, 2C, and 2D, antenna 30 is shown in further detail. In the illustrated embodiment, antenna 30 has five panels 52 that are used to direct communication signals to a desired direction. As is illustrated best in Figure 2A, each panel 52 has a field of view and a scanning range slightly narrower than the field of view. Each panel is preferably a flat panel that allows cost effective multiple connectivity from base station 18 to the various users. Each panel 52 is used to establish multiple dynamic links. In combination, the various base stations together are used to form the communication signal

with the users. Thus, multiple base stations through multiple panels 52 of antennas 30 are used in each communication. The bandwidth on demand is accomplished not by a variety of data rates via a single rf link but through different data rates resulting from various combinations of multiple dynamic rf links. As will be further described below, as the user moves, some links may fade away while new links may become available. Thus, multiple links will always be connected to a user. As illustrated, five panels are used, however, those skilled in the art will recognize various numbers of panels may be used.

[0041]   As is best shown in Figure 2B, panels 52 have an angle 54 relative to the horizontal. Angle 54 allows the communication signals generated at panels 54 to be directed slightly downward toward the earth's surface. Of course, angle 54 depends on the height of base station 18 above the earth's surface. That is, as the height of the tower increases, the angle 54 decreases. The angle is such to give a desired service area for each panel 52.

[0042]   In operation, the combination of simultaneous multiple beam capability on both the mobile terminals and base stations will make overall mobile systems even more cost effective. A user through their associated multiple beam user device or appliance will connect to an IP network by establishing multiple dynamic links through various base stations to the communication nodes of the Internet. As a result, precious mobile spectrum may be reused many times when mobile subscribers use directional antennas. The same amount of spectrum can be used again and again to increase the bandwidth density (i.e., total bandwidth a mobile system can project into a unit area). Therefore, the system will provide more throughput for users and larger capacity for the operators, and more efficient utilization for regulators. Providing a high gain on both user terminals and base stations allows the cell size to be extended extensively without impacting the bandwidth density. The bandwidth on demand will be implemented through multiple dynamic links and thus multiple links will always be available to a user. There may be many bases stations within a field of view of a mobile user. For example, there may be as many as between five and ten bases stations within a user's field of view. A user with an omni directional terminal may connect to one nearest base station with an rf channel (specified by frequency, time and/or code). This channel will not be assigned to other users as in a conventional cellular system. Adaptive

antennas on base stations allow operators to use the same channel again within the same "cell" but via different base stations, provided the base stations have the capability to directionally discriminate against interferences at the same channel as that intended user but at different directions. As will be further described below, the user and interference sources must be located reasonably far to make the adaptive technique effective. The base stations may include circuitry to null or offset interferences between the communication signals. During an acquisition phase, e.g., from a cold start, all received beams will be "on" to cover the entire field of view of a fan beam. Thus, the various beams will have different elevation angles and azimuth angles to cover the search volume. Once a user link is established, only nearby beams from a particular panel 52 may be activated.

[0043]   Once a user link is established, the tracking mechanism uses a type of step scan principle. The signal strengths from adjacent received beams will be monitored and compared with one coming from the main beam. The beam with the strongest signal will be identified as a "locked" or main beam. As a user moves, the tracking base station may switch (i.e., step) a received beam from one position to an adjacent one with the strongest signal, and assign the transmit beam accordingly.

[0044]   As is best shown in Figure 2C, a panel 52 may be comprised of a plurality of radiation elements or patches 56. Radiation elements 56 may, for example, be described as a "patch array." As is illustrated, 90 elements are illustrated in Figure 2C. Each element 56 has a diameter of 0.3 wavelengths. Element modules are placed at slightly less than 0.7 wavelengths apart in a nearly square lattice. Panel 52 may also be referred to as an "aperture." Panel 52 has a radiating area in the order of about 25 square wavelengths. The expected peak gain of a beam is 24dB at the boresight, and about 22dB at 45 degrees away from the boresight. Beam widths for the boresight elliptical beam is about 10 degrees in azimuth and 15 degrees in elevation respectively. The beams are dynamic and therefore assigned to track individual subscribers accordingly.

[0045] Referring now to Figure 2D, a 45 element panel 52 is illustrated. Such a panel has about 3dB less gain than that of the panel illustrated in Figure 2C while maintaining about the same directional discrimination.

[0046] Referring now to Figure 2E, another element configuration of a flat panel 52 is illustrated for a high frequency application. In this embodiment, panel 52 has about 36 elements. In this embodiment, each element is approximately 0.6 wavelengths in diameter with element spacing slightly less than 0.7 wavelengths apart in a nearly square lattice. The total aperture has a rating area in the order of about 10 square wavelengths. The peak expected gain of the beam is about 20dB at boresight and 18dB 45 degrees away from the boresight. The beam widths for the boresight elliptical beam are about 5 degrees in azimuth and 15 degrees in elevation, respectively. Therefore, at 2 kilometers away from the base station, the beam width and azimuthal direction is about 200 meters. Of course, fewer elements may be used depending on the frequencies involved. That is for higher frequencies because more data is transferred, less elements may be required to match the processing power of the circuitry.

[0047] For each of the above embodiments, long baselines, not full apertures, over a large bandwidth provide good directional discrimination capability. The thin array at a single frequency will exhibit high side lobes or semi-grading lobes. Over a large bandwidth, side lobes arise at various directions at different frequency components. As a result, the integrated interference contribution from side lobes over a large bandwidth tends to smear out or cancel while the contribution to the main lobe over the same bandwidth may be constructively added together. As will be further described below, additional cancellation schemes may be applied to reject interferences for all beams tracking to various subscribers if necessary.

[0048] Referring now additionally to Figure 3, radiating elements 56 form modules 58 which are plugged into panels 52. Panels 52 serve as back plates which are interconnected through a bus 60. Bus 60, for example, may include a DC power line 62, an inflow data line 63, an outflow data line 64, an address line 65, and a control line 66. Panels 52 may be modularized and include sockets for easy connection and disconnection of modules 58. Each

panel or back plate 52 may include a processor 68 to handle beam configuration. Processor 68 may be part of controller 36 described above in Figure 1.

[0049]   Referring now to Figures 2E and 4, a beam pattern 69 for the panel of Figure 2E is illustrated. The pattern 69 has circles 70 or ellipses representing beam positioning patterns from a dynamic beam allocation and positioning scheme, while the hexagon 71 representing fixed beam positions from a conventional static cell system. Panel 52 converts the received microwave power into a digital stream in the receiving direction and converts the digital stream into radiated microwave power in the transmitting direction. The phasing of various elements is implemented by digital multiplication in a separated digital beam former. The digital beam forming approach eliminates the need of conventional phase shifters and minimizes required rf components, making possible a low cost implementation suitable for the consumer market.

[0050]   Referring now to Figure 5, a digital beam forming circuit 72 is illustrated for a base station (of Figure 1). However, a similar beam forming circuit may also be used for a user device. Also, a receive beam forming network is shown, however, those skilled in the art will recognize a corresponding transmitting beam forming circuit may be formed in reverse.

[0051]   Digital beam forming circuit 72 has a plurality of elements 74. Various groupings of elements 74 are used to generate the simultaneous multiple links of the present invention. Each element 74 is coupled to a corresponding analog-to-digital converter. As those skilled in the art will recognize, a band pass filter (not shown) may also be coupled between element 74 and analog-to-digital converter 76. The digital outputs from all of the analog-to-digital converters 76 are weighted and summed, then grouped together to form beams 1 through M as illustrated. The beams are formed by numerical multiplications using the direction vector beam 1 as illustrated as reference numeral 78 and through direction vector beam M as illustrated by reference numerals 80 through forming circuit 82. Forming circuit 82 may have a plurality of multiplication blocks 84 and summing blocks 86 either implemented physically or in software to form the various beams. Functions of beam

forming, frequency tuning and time synchronization are interlaced to minimize the over processing mode, instead of sequentially. This approach eliminates conventional phase shifters and minimizes the required rf components making the implementation suitable for consumer applications. Digital beam forming circuit 72 is used to generate multiple simultaneous links with base station 18. The digital beam forming circuit 72 is configured such that a unique beam is assigned for each individual user. The base stations will track users with unique channels and beam positions. Every user will have a bubble which is the beam size associated with the assigned beam. The bubble forms an exclusion zone associated with each user for a specific channel. Users assigned with the same channel can co-exist in a network as long as their associated bubbles do not intercept one another. When bubbles for a particular channel collide, one user is assigned a new channel.

[0052]   Direct samplings are used to simplify the architecture. Low cost is achieved by the use of an analog-to-digital converter 76 that allows analog-to-digital conversion of the received signals at rf directly allowing other processing to be performed digitally. High speed and low speed analog-to-digital conversion will over sample the received signals. In one constructed embodiment, a user signal is assumed to be about 5MHz but could go as high as 30MHz. A sampling rate was chosen to be about 20MBps per second with approximately a 4-bit resolution. Aperture time of the analog-to-digital converter must less than one-eighth of the period of the carrier frequency. Therefore, at a 2GHz carrier frequency, the aperture time of about 50 picoseconds is adequate.

[0053]   Referring now to Figure 6, an alternative to the circuit configuration of Figure 5 is illustrated. In this embodiment, the number of analog-to-digital converters is reduced and the dynamic range required for the individual analog-to-digital converters is also reduced. In the circuit of Figure 6, element 74 may be weighted in block 88 before a summer 90. Summer 90 is used to group a number of elements together. Each summing block 90 has an analog-to-digital converter 92 associated therewith. Thus, by grouping a number of elements together with a summing block 90, the number of analog-to-digital converters is thus reduced. Each summing block 90 may also be connected to a noise injection circuit 94. Structured noise may be added to the summing block 90. The structured noise may consist of

orthogonal codes. A similar technique is described in U.S. Patent 5,077,562 which is incorporated by reference herein.

[0054]   Each analog-to-digital converter 92 is coupled to demultiplexer 96. Demultiplexer 96 is coupled to digital beam forming and interference rejection network 98. Demultiplexer 96 demultiplexes the outputs from analog-to-digital converters 92 and provides them to digital beam forming and interference rejection network 98. Digital beam forming and interference rejection network provides a received signal to be processed by the processing center.

[0055]   Referring now to Figure 7, a similar embodiment to that shown in Figure 6 above is illustrated. In this embodiment, a portion of the circuit may be located in base station while the remaining portion of the circuit may be located in a processing center. By removing some of the circuitry from a base station, a less costly and more flexible system may be obtained. The same reference numerals are used for the same elements in Figure 7 as in Figure 6. Elements 74 are coupled to weighted block 88 which in turn are coupled to summers 98. A weighted block 100 is used after summer to couple summer 90 with a central summing block 102. The signal from summing block 102 is thus broadcast or transmitted to the gateway station for further processing.

[0056]   Referring now to Figure 8, a gateway portion 104 of the circuit illustrated in Figure 7 is illustrated. A demultiplexer 96 similar to that illustrated above is used. Demultiplexer 96 demultiplexes the broadcast signal from summer 102 and provides it to an analog-to-digital converter 106. Analog-to-digital converter 106 may be coupled to noise injection circuit 108. Noise injection circuit 108 may be similar to that described above in that noise injection circuit 108 may use orthogonal codes. The output of analog-to-digital converter is provided to a demultiplexer portion 108 which in turn is coupled to digital beam forming and interference rejection network 98 similar to that in Figure 6. Thus, digital beam forming network and digital interference rejection network provides received signals from the various beams. By providing the demultiplexing analog-to-digital conversion and noise injection all in one location such as the gateway station, the complexity of the base stations

may be reduced. Further, the number of elements provided at a base station may be increased due to the remote processing of the beam signal.

[0057] Referring now to Figure 9, a more detailed processing scheme for a CDMA system, such as 3rd generation mobile, from that shown in Figures 8 is illustrated. In this embodiment, a diplexer 110 is connected to a radiator (not shown) so that both transmit and receive signals are through the same radiator. Only the receive functions are illustrated. The corresponding transmit functions are identical but in a reversed direction. The received multiplexed signals are coupled to an analog-to-digital converter 112. To simplify the block diagram, we did not include the noise injection portion in here. Following analog-to-digital converter 112 a element code despreading circuit 114 has a plurality of multiplication blocks 116 which performs the matched filter function via a multiplication 116 and a band pass filter 118, to recover the signal received at a specific array element in digital representation. Therefore at the outputs of the de-spreading block 114, the received signals of all the array elements at the remote base stations have been re-generated in digital forms. The regenerated signals are available for further processing.

[0058] A scheme in which every user will have a dedicated beam is illustrated. The received element signals by user codes are sorted element by element before beam forming. More than one user per code is used but they come from different directions and arriving at different time.

[0059] Element code despreading circuit 114 is coupled to a user code despreading circuit 120. Each user code is used to group multiple users with the same user code together in user code despreading circuit 120. Different users may only be separated via time delay and direction of arrival. Thus the block 120 must provide digital streams with multiple taps to beam forming network so that the user signals with the same user code can be separated via time and directional "filtering processes." Each user code from user code despreading circuit 120 is coupled to digital beam and null forming network. One digital beam and null forming network is provided for each user. Track files 124 provide input to digital beam forming and null forming network 122. Track files include information such as the user code, the

location, timing and orientation of the users. Track files allow the communication signals to be divided into several links for communication through a number of base stations. The user signals after digital beam forming are output and coupled to such things as the Internet. Feedback is provided from output 126 through an extended Kalman filter. The extended Kalman filter 128 is used to update each user position channel and potential for interference or collision with neighbors. The information from the extended Kalman filter 128 will be used to track the corresponding user.

[0060] Referring now to Figure 10, an adaptive nulling circuit 130 that could be used with any of the circuits in Figures 7 through 9 is illustrated. For example, the circuit 142 of Figure 10 may be implemented as a part of element 122 of Figure 9. Circuit 130 has elements 132 which are coupled to a beam forming circuit 134 and an analog-to-digital converter 136. Of course, as mentioned above, this portion of the circuit may be similar to that shown in Figures 7 through 9. A multiplication block 138 and amplifier 140 may also be included in the circuit. A digital beam forming and nulling processor 142 is coupled to each analog-to-digital converter. Each signal is multiplied by a weight at multiplication block 144 prior to being summed at a summer 146. The output of summer 146 is the output signal $Y_{(t)}$. In a typical digital beam forming, the directional vector (the multiplier set) is pre-determined by pointing direction only, and usually will exhibit a linear phase progression on the array apertures for spot beams . However, in the adaptive beam forming and nulling network illustrated, the directional vector will be further modulated by signal environment, such that a beam is directed toward desired user while nulls are steered toward high interference directions. As a result the received signal to noise (including interference) ratio is "maximized." Negative feedback block 147 is provided from output signal $Y_{(t)}$ to a multiplication block 148 for each signal. The multiplication block 148 multiplies the input signal from each analog-to-digital converter with the output signal $Y_{(t)}$. A sum through summer block 150 is provided to a weight update block 152. Weight update block 152, thus in response to the multiplication block 148, updates the weights and provides those to multiplication blocks 144. The output is thus,

$$Y(t) = \Sigma_i W_y \widehat{S}_i(t)$$

$$\frac{dw}{dt} = -\alpha \nabla_w \varepsilon$$

$$(\nabla_w \varepsilon)_1 = 2 \langle y(t) - d(t) * S_1(t) \rangle$$

[0061]   Our method for adaptive nulling to use a least mean square criteria for steady state solution. In addition, a steepest descent technique may be used to reach the steady state solution. An indirect correlation technique is used, rather than a direct perturbation technique, to measure the "gradients" for each update.

[0062]   Referring now to Figure 11, to reduce cost and enhance the nulling efficiency, a limiter may be placed in the feedback path similar to the techniques described in U.S. Patent 4,635,063, which is hereby incorporated by reference. Limiting circuit 160 includes elements 162 similar to those described above. Each element has an associated main channel 164, a feedthrough path 166, and a feedback path 168. Since the circuitry associated with the respective elements are essentially the same, the circuitry associated with only one sensor is referenced in detail. The function blocks can all implemented in digital format. For Instance, power dividers correspond to data bus, weight circuits to multipliers, correlators to processors combining multipliers and integration-&-dumps, outputs of hard limiters to sign bits, and so on.

[0063]   Correlators 170 co-process signals in the feedthrough path 166 and feedback path 168; the result is transformed according to an algorithm by a computer 172. The weighting circuit 174 thus progressively modifies the signal in the main channel 164 to minimize interference with a desired signal.

[0064]   A limiter 176 is placed along feedback path 168. As explained below, this placement simplifies correlator design relative to the circuit without such limiters and improves performance relative to adaptive antennas with limiters in the feedthrough path.

[0065]   Each element 162 is connected via the respective main channel 164 to respective input power divider 180 or other means for dividing an input signal between a pre-

processed signal and a diagnostic signal. A diagnostic signal is conveyed along the respective feedthrough path 166; the pre-process signal is conveyed along a second portion 182 of the respective main channel 164.

[0066] The amplitude and phase of pre-process signals may be modified by weighting circuit 174 or other weighting means associated with each of the elements 162. The resulting weighted signals are directed along a third portion 184 of respective main channel 164 to be summed by means such as a power combiner 186. Means such as an output power divider 188 inserted along a unified portion 190 of main channel 14 between the power combiner 186 and antenna output 192, divides the summed signal between an output signal and a feedback signal.

[0067] The illustrated feedback path 168 includes means for eliminating from the feedback signal the desired band of frequencies associated with the primary signal source to be received by circuit 160. This means may include a hybrid 194 for subtracting the desired band from a portion of the summed signal. More particularly, hybrid 194 includes a primary input 196 and a secondary input 198. The primary input 196 receives a portion of the summed signal from output power divider 188. The secondary input 198 receives only the part of the summed input with the desired band. The desired band may be provided by means of a band pass filter 200, the input of which is a portion of the summed signal directed thereto by output power divider 188. The output of hybrid is the summed signal less the desired band. The elimination of the desired band from the feedback signal avoids possible nulling against the desired signal source. The limiter 176 is located in feedback path 168 so that limiting occurs prior to division of the feedback signal. Thus, the need for plural limiters is obviated. Preferably, limiter 176 is a hard limiter. Ideally, a hard limiter transforms a sinusoidal input to a square wave output.

[0068] The limited feedback signal is divided by means such as power divider 202 to provide feedback signals to provide feedback inputs 204 of correlators 170. The feedback signal is correlated with the diagnostic signal received at feedthrough input 206 of each correlator 170. The preferred correlator 170 is a multiplier coupled with a low pass filter.

[0069]   Each correlation resultant is transformed according to an algorithm by computer or processor 172 or alternative means. The transform is used to determine the weighting function of the weighting circuit 174 or other weighting means. Preferably a gradient descent algorithm such as least means square error, Howell-Applebaum power inversion, is used.

[0070]   Some of the advantages of the present invention can be better understood in accordance with the following theoretical analysis. The function of the ideal hard limiter is to produce a high constant level positive output whenever the input is positive and a low constant level negative output whenever the input is negative. The transition between the constant positive and negative output values (or the threshold values) is a sharp or discontinuous one. Therefore, with a sinusoidal input the output would ideally be a square wave. In a multiple signal environment where the signal power differences are large (e.g., more than 10 dB), the limiter will suppress weaker signals and enhance the strongest signal. Qualitatively, the limiter will only respond to the strongest signal.

[0071]   In a phased array geometry, each element shares the same field of view as every other element. Therefore, each element plays a nearly equal role in forming a single beam. All jamming signals in the field of view are sensed by every single element in the phased array. Consequently, the positioning of the limiter in either the feedthrough path or the feedback path is critical for multi-interference rejection in the phased array.

[0072]   If the limiter is placed in the feedthrough path, its output will have merely the information of the strongest interference, and the antenna system will null against the strongest interference accordingly. The correlator outputs will not include any of the other interference signal information to allow the antenna system to form nulls in their directions.

[0073]   Alternatively, when a hard limiter is placed in the feedback path, the antenna system can first null against the strongest interference signal until it becomes comparable to the second strongest. The antenna system will then null against both until the antenna system

reaches an inherent threshold level, created by quantization error or feedback loop gain, limiter, etc.

[0074]   Figure 12 shows a comparison of the interference suppression performance and the convergence rate of three four-element phased array configurations: (a) no limiter, (b) limiters in the feedthrough path, and (c) limiter in the feedback path. These results were obtained from a computer simulation program, ADAPT and are the dynamic spectral output versus the number of iterations of the adaptive process.

[0075]   As the adaptive process proceeds from the initial state in the configuration with no limiter, the strongest interference is monotomically reduced until it is below the threshold value at iteration 37, as show in Figure 12A. The threshold value is set 35 dB below the strongest interference. The weaker interference was not a driving force until iteration 34. At this point, the weaker interference is slowly but continuously suppressed. At iteration 126, the interference signal is below the threshold value. During the adaptation, the desired signal power density at the output is continually being enhanced until it reaches a steady state value of 10 dB above the threshold at iteration 134. The system configuration works but it needs high dynamic range correlators. In order to reduce high dynamic requirement on correlators, limiters are incorporated in the many modified options, as shown below.

[0076]   In the configuration with the limiter in the feedthrough path, the power density level of the stronger interference is successively reduced below threshold but the power density level of the weak interference increases initially and remains at that steady state value as shown in Figure 12B. The desired signal increases slightly in value, but is never enhanced above the weak interference. This system does not respond adequately to the weaker interference signals.

[0077]   In the configuration with the limiter in the feedback path, the power density levels of both the weak and strong interference are successfully reduced below the threshold as seen in Figure 12C. As compared to the configuration with no limiter, the weaker

interference is suppressed slightly faster. The weak interference is below threshold at iteration 87. Throughout this process, the desired signal is continuously enhanced.

[0078]   In accordance with the above, it can be seen that the present invention provides for improved performance over the no-limiter and limiter in the feedthrough path designs of the prior art. The present invention further improves on the feedthrough limiter version by requiring only one limiter, and improves upon the no-limiter version in relieving the design requirements on the correlators.

[0079]   Referring now to Figure 13, another circuit 220 to provide nulling is illustrated. In this embodiment, a plurality of main array elements 222 and auxiliary elements 224 is illustrated. Main array elements 222 are similar to the elements described in the previous circuit. Auxiliary elements 224 have been added to provide canceling of side lobes from the main elements. This will provide the capability to allow users to be closer together without interference. Main array elements 222 are coupled to a main digital beam forming circuit 226. Auxiliary elements 224 are coupled to an auxiliary digital beam forming circuit 228. A summing block 230 sums the signals from the main array elements through main digital beam forming circuit 226 with weighted portions of auxiliary elements to cancel interference. Feedback is provided through a weight update block 232. Weight update block 232 generates a weight for each of the user signals and provides them to a multiplication block where they are combined with the output of auxiliary digital beam forming circuit 228. The output of digital beam forming circuit may also be coupled to weight update block 232 to allow the weights to be formed as a function of the auxiliary digital beam forming input. The weighted auxiliary digital beam forming signals are combined in a summer 234 where they are combined with each of the auxiliary digital beam forming circuits and provided summer 230 for providing interference cancellation. Thus, output 236 of circuit 220 has the main user signals interference compensated for by the auxiliary elements 224.

[0080]   In operation of Figure 13, main array elements 222 are used to generate the communication beams of the present invention. The auxiliary elements 224 are used to cancel interference from the main array elements as needed. That is, by using the positions of

the users, weights may be determined for auxiliary elements 224 so that the auxiliary elements 224 will have an auxiliary element output to cancel interference from the communication beams because of the direction of strong interfering sources for each active beam may be determined from the user position. Preferably, this is performed in the gateway station to prevent complexity in the base station. As those skilled in the art will recognize, it is the side lobes of the main beam that are to be canceled. By providing the auxiliary elements, the side lobes of the main beams may be reduced or selectively canceled by the auxiliary element outputs. Each panel described above may include canceling of the side lobes using auxiliary elements.

[0081]   Advantageously, by providing the digital beam forming in the gateway station, all of the beams are formed in a real time manner using the user position files that exist in the gateway station. As the system needs change, the gateway station may adaptively change the output of the auxiliary elements on a continual basis.

[0082]   While the best modes for carrying out the invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.